Enhancing Cloud Droplet Number Concentration Representation in Global Climate Simulations

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Introduction

- Aerosol-cloud interactions (ACI) are currently the largest uncertainty in climate simulations, with major effects on radiative forcing projections
- Cloud Droplet Number Concentration (N_d) critically controls ACI by influencing cloud albedo, precipitation, and evaporation
- The Cloud AeroSol Interaction Microphysics (CASIM) double-moment cloud microphysics scheme is well established in high-resolution simulations and is applied to the UK Met Office Unified Model (UM) global model to improve droplet representation [5]

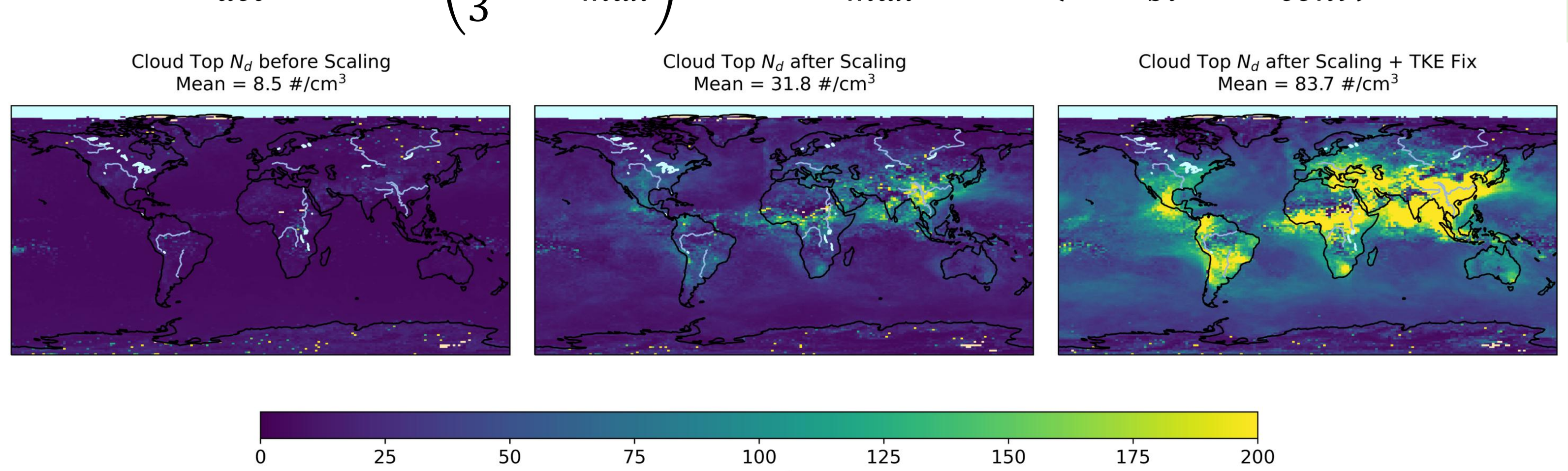
Methods

- Global simulations are run at a resolution of 1.875°x1.25° (lon x lat) for February and July 2018 (monthly analysis) and for the full year 2018 (annual analysis)
- Simulated N_d is output from CASIM and derived using the CFMIP Observation Simulator Package (COSP) for internal comparison
- Model validation from satellite-derived N_d comes from Gryspeerdt et al. (2022), which uses MODIS retrievals to calculate and post-process N_d with multiple masking techniques

Updraft Tuning for Aerosol Activation

- CASIM uses the prognostic Abdul-Razzak and Ghan (2000) aerosol activation parameterization, where turbulent kinetic energy (TKE) and its scaling factor (c) are used in the calculation of activation updraft velocity (w_{act})
- To increase N_d above the surface, we linearly scale c from zero at the surface to one at 200 m and add convective TKE into activation

$$w_{act} = w + c\left(\frac{2}{3}TKE_{max}\right)^{0.5}, \quad TKE_{max} = \max(TKE_{bl}, TKE_{conv})$$

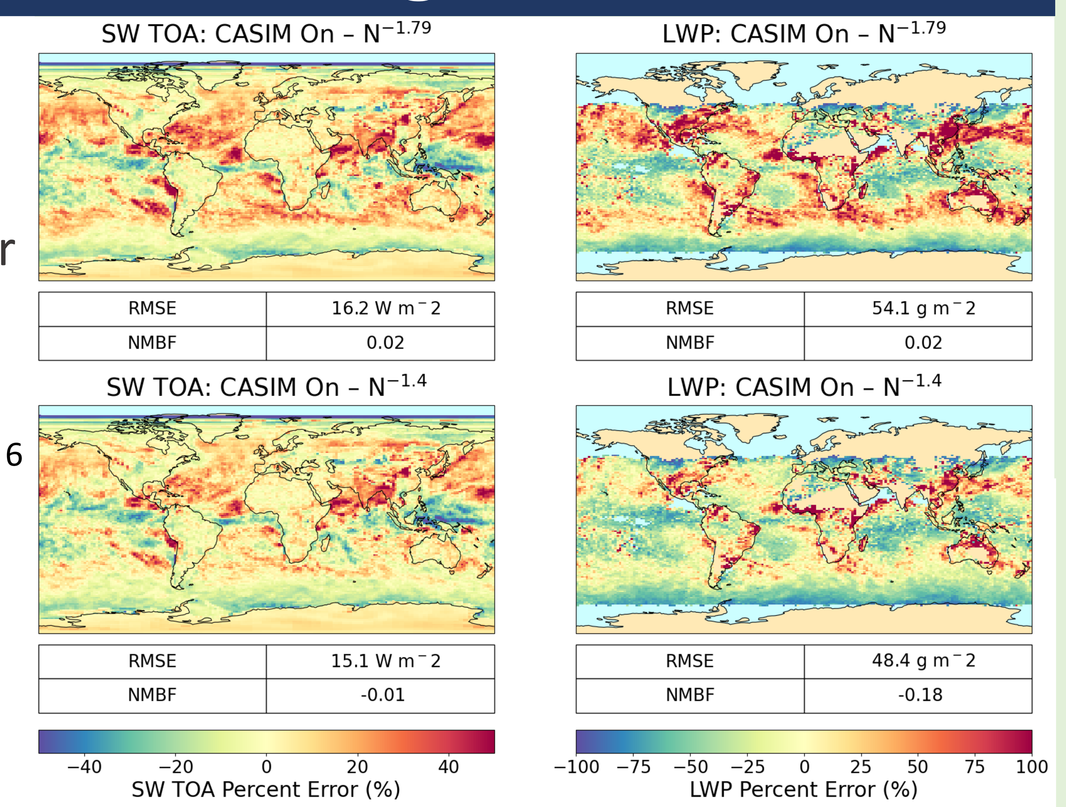


Autoconversion Tuning for CASIM

- Autoconversion rate is enhanced to improve radiation and liquid water path biases

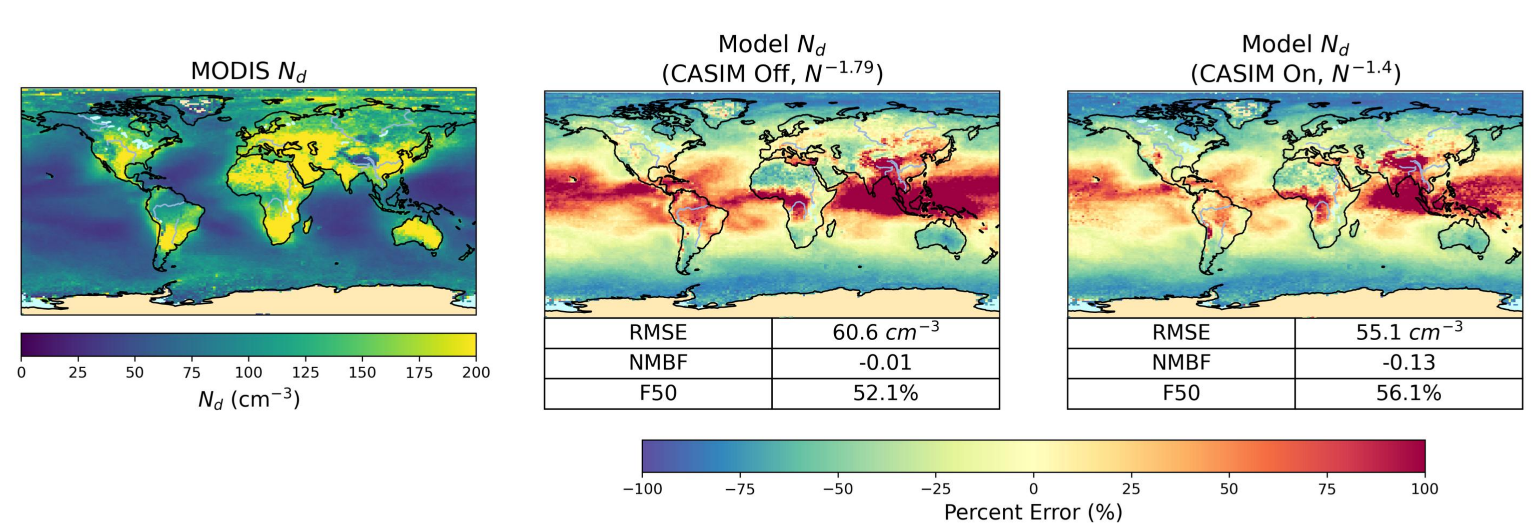
$$\left(\frac{\delta q_r}{\delta t}\right) = 1350 q_w^{2.47}\left(\frac{\rho N_d}{10^6}\right)^{-1.79} \quad (6)$$

(-1.79 is default in KK2000)



Annual Performance of CASIM N_d

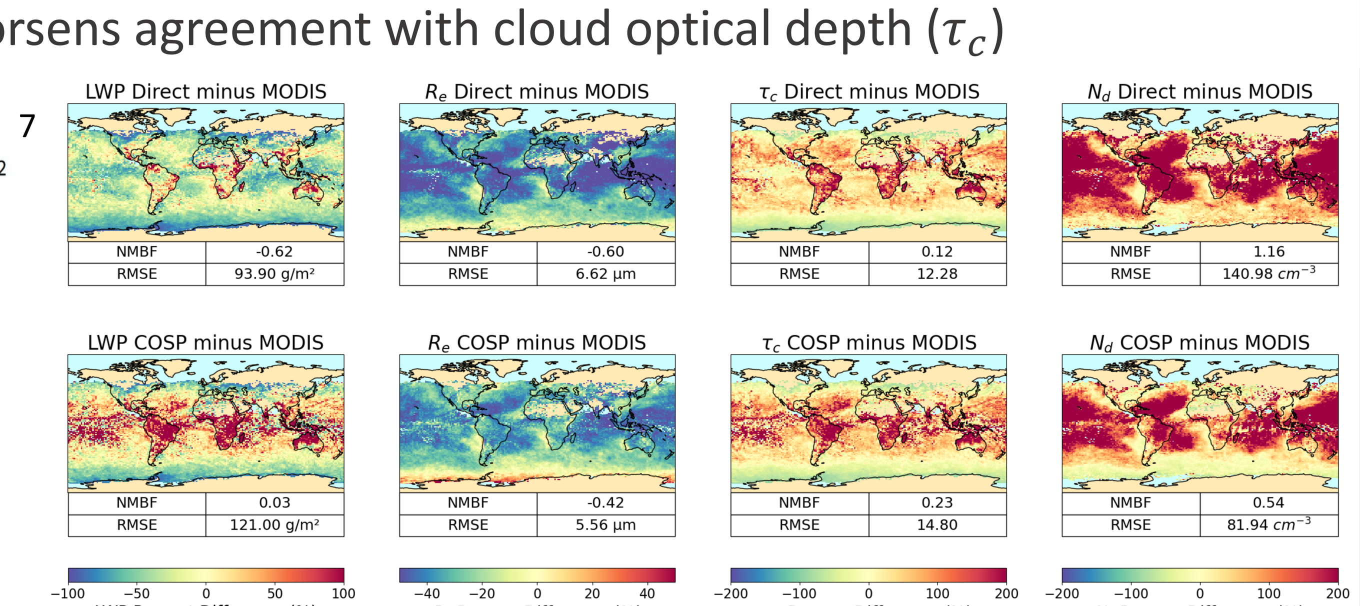
- Annual mean cloud top N_d from CASIM is compared with that of the default single-moment global cloud microphysics scheme of Wilson and Ballard (1998)
- CASIM improves the UM's root mean squared error by 15.5 cm^{-3} in the tropics and 5.5 cm^{-3} globally



Use of the COSP Satellite Simulator

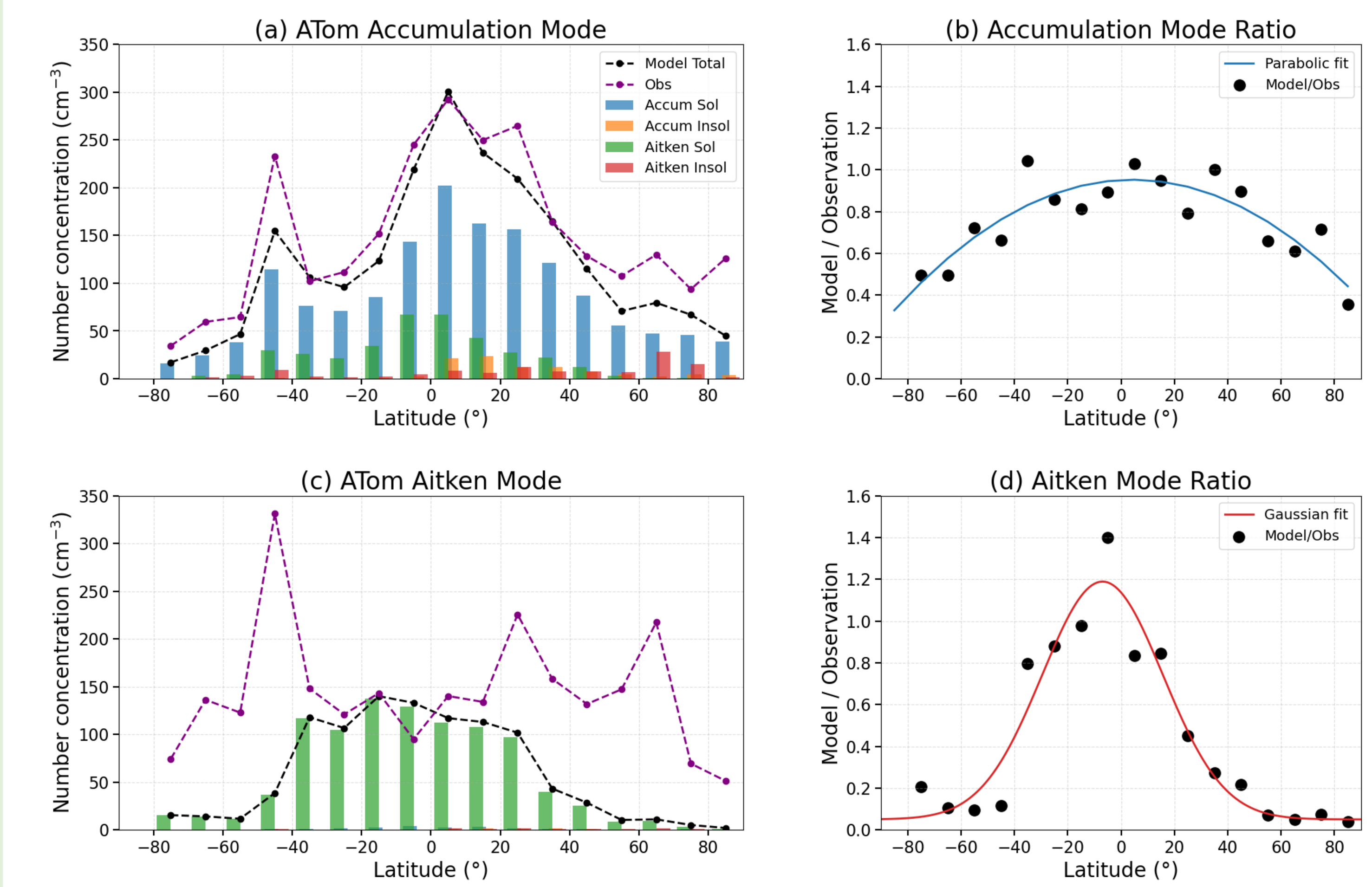
- COSP uses both macrophysical and microphysical inputs from the UM radiation scheme
- COSP improves model agreement with remotely sensed effective radius (r_e), but worsens agreement with cloud optical depth (τ_c)

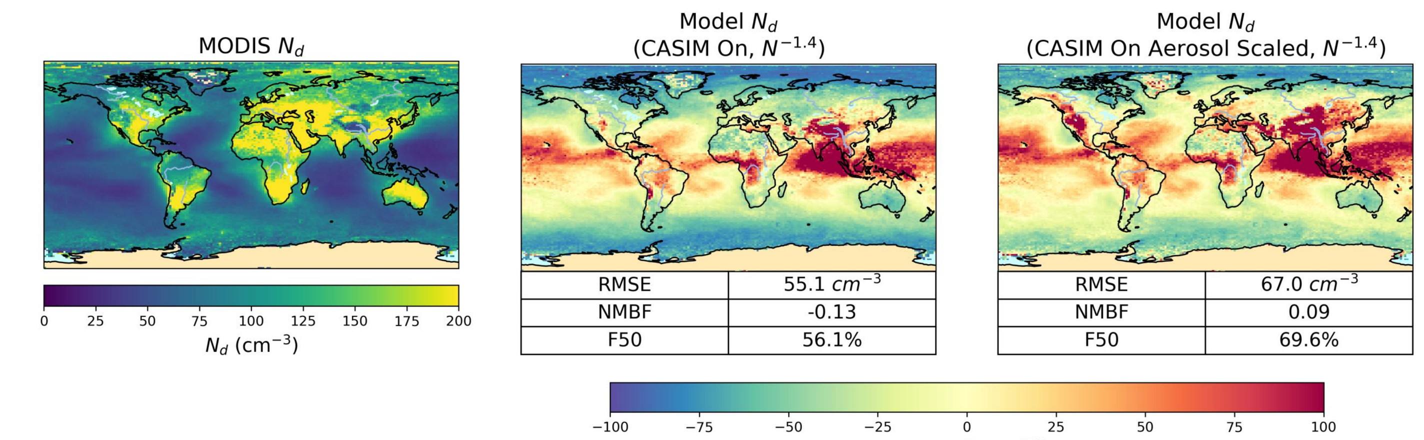
$$N_d = \frac{\sqrt{5}}{2\pi k}\left(\frac{f_{ad}\, c_w\, \tau_c}{Q_{ext}\, \rho_w\, r_e^5}\right)^{1/2} \quad (7)$$



Analysis of Simulated Aerosol

- Simulated Aitken and accumulation mode aerosol concentrations are compared to observations from the NASA Atmospheric Tomography (ATom) Mission across a full range of latitudes
- At high latitudes, the UM underestimates accumulation mode number concentration by ~ 2x, Aitken by ~10-20x
- Applying an aerosol correction factor to CASIM reduces high-latitude N_d biases by ~60%, but activation-related biases persist





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References

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